Cognitive load theory and multimedia learning, task characteristics, and learning engagement: The current state of the art

DOI:
10.1016/j.chb.2010.05.003

Document status and date:
Published: 01/01/2011

Document Version:
Peer reviewed version

Running head: COGNITIVE LOAD THEORY AND MULTIMEDIA LEARNING, TASK CHARACTERISTICS AND LEARNING ENGAGEMENT

Please refer to this article as: Kirschner, F., Kester, L., & Corbalan, G. (in press). Cognitive load theory and multimedia learning, task characteristics, and learner engagement: The current state of the art. *Computers in Human Behavior*. doi:10.1016/j.chb.2010.05.003

Cognitive Load Theory and Multimedia Learning, Task Characteristics and Learning Engagement: The Current State of the Art

Femke Kirschner[1*], Liesbeth Kester[2], and Gemma Corbalan[3]

[1]Institute of Psychology, Erasmus University Rotterdam, the Netherlands

[2]Centre for Learning Sciences and Technologies, Open Universiteit in the Netherlands

[3] Department of Research and Advice, The Netherlands Institute for Curriculum Development, Enschede, The Netherlands

[*] Correspondence concerning this article can be sent to Femke Kirschner, Institute of Psychology, Erasmus University Rotterdam, The Netherlands, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands, e-mail address kirschner@fsw.eur.nl

Cognitive Load Theory and Multimedia Learning, Task Characteristics, and Learning Engagement: The Current State of the Art

This special issue consists of 16 empirical papers, as well as a discussion based on the Third International Cognitive Load Theory Conference held at the Open Universiteit (Heerlen, The Netherlands) in 2009. All papers focus on improving instructional design from a cognitive load theory (CLT: Sweller, 1988; Sweller, Van Merriënboer, & Paas, 1998; Van Merriënboer & Sweller, 2005) perspective. They cover a wide variety of topics in which learner characteristics, tasks characteristics, and the interaction between both are studied in, new, innovative, but also traditional ways, thereby providing an overview of the current state of the art on CLT research. The overarching goal of all studies is to gain more understanding and insight into the optimal conditions under which learning can be successful, and students will be able to apply their acquired knowledge and skills in new or familiar problem solving situations. Together, the papers comprise three ways in which this overarching goal is reached: (1) by studying *multimedia learning environments*, (2) by studying *different characteristics of a learning task* and, (3) by studying how learners can be *actively engaged in the learning process*. Although, the research focus of most papers fit nicely within these research topics, some overlap is inevitable. The categorization has been made on the basis of the most prominent research focus and findings of each study.

This editorial starts by describing some of the basic principles of CLT, and then describes the three current research topics by providing a brief overview of the individual papers per topic and the discussion paper which is the clincher of this special issue.

Cognitive Load Theory

If learners are to learn effectively in any given learning environment, the architecture of their cognitive system, the learning environment, and interactions between both must be understood, accommodated and aligned. This central notion of CLT resulted, on the one hand, in the identification of viable instructional design principles such as the worked example, completion, split-attention, modality, redundancy, imagination, goal-free, and expertise reversal effects (for reviews see Sweller, 2004; Sweller et al., 1998). On the other hand, it broadened our understanding and knowledge about human cognitive structures, like the overwhelming importance of long-term memory (Sweller, 2004), or the role of the mirror neuron system (Paas, Van Gog, Kirschner, Marcus, Ayres, & Sweller, 2008; Van Gog & Paas, 2009). The large body of cognitive load based research already has provided us with valuable understanding of how, when and why some learning environments are more effective and efficient for learning than others. However, the characteristics of such learning environments as well as the learners who participate in them are so diverse and abundant that relevant research will not soon draw to an end.

CLT focuses on complex cognitive tasks, in which instructional control of cognitive load is critically important to meaningful learning. To realize this control, CLT uses current knowledge about the human cognitive architecture to generate instructional techniques. This architecture consists of an effectively unlimited long-term memory (LTM), which interacts with a working memory (WM) that is very limited in both capacity (Baddeley & Hitch, 1974; Miller, 1956) and duration (Peterson & Peterson, 1959). For new, yet to be learned information, the processing capacity is limited to only 4 plus or minus 1 element, and if not rehearsed, the information is lost within 30 seconds

(Cowan, 2001). LTM contains cognitive schemas that are used to store and organize knowledge by incorporating multiple elements of information into a single element (also referred to as chunking; Chase & Simon, 1973; Miller, 1956; Simon, 1974) with a specific function.

Learning occurs if information is successfully processed in WM and because of this, new schemas are created (i.e., schema construction), new elements of information are incorporated into consisting schemas (i.e., assimilation), elements consisting of lower level schemas are combined into higher level schemas building increasing numbers of ever more complex schemas (i.e., schema elaboration), and existing schemas based upon recurring new information which are incongruous or inconsistent with existing schemas are adapted (i.e., accommodation) (Van Merriënboer & Kirschner, 2007). If the learning process has occurred over a long period of time, the eventual schema may consist of a huge amount of information. Empirical evidence of this can be found in the study of chess grandmasters (De Groot, 1946; 1978; Simon & Gilmartin, 1973) who stored enormous amounts of board of chess pieces taken from real games in their LTM, making them the experts they are. Because a schema can be treated by WM as a single element or even bypass WM if a schema has become sufficiently automated after long and consistent practice, the limitations of WM disappear for more knowledgeable learners when dealing with previously learned information stored in LTM.

Overcoming individual WM limitations by instructional manipulations that are compatible with human cognitive architecture has been the central focus of CLT. Cognitive load research is therefore mainly concerned with the development of techniques for managing WM load imposed by a learning task, thereby facilitating the changes in LTM associated with schema acquisition and automation (i.e., learning) which is needed to transfer acquired knowledge and skills to new problem-solving situations.

The cognitive load learners experience when working on a learning task can be caused by the intrinsic nature of the task or by the manner in which the information within the task is presented to them. ‘Intrinsic’ load is imposed by the number of interactive information elements in a task. The more elements there are within a learning task and the more interaction there is between them, the higher the experienced intrinsic cognitive load will be. The manner in which the information is presented to learners can either impose an ‘extraneous’ or ‘germane’ load. Extraneous load is imposed by information and activities that do not directly contribute to learning, while germane load is caused by information and activities that foster learning processes. The three loads are additive and it is important to realize that the total cognitive load associated with an instructional design should not exceed the available WM processing capacity (Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Sweller et al., 1998) for learning (i.e., schema acquisition and automation) to be effective.

When managing the total cognitive load to facilitate learning and transfer, first of all, extraneous load must be eliminated. Studying worked examples (instead of solving conventional problems) has been identified as an effective way of reducing extraneous load, because the learner can devote all available WM capacity to studying a worked-out solution and constructing a schema for solving similar problems in LTM (e.g., Atkinson, Derry, Renkl, & Wortham, 2000; Sweller, 1988). However, freeing WM capacity by eliminating extraneous load is not a sufficient technique for instructional conditions to be effective. Therefore, as a next step, a balance must be found between intrinsic load and germane load. This means that intrinsic load must be managed in such a way that the simultaneous processing of all interactive information elements leaves some spare cognitive capacity and that learners are encouraged to invest free processing resources in schema acquisition and automation, evoking germane load (Paas, Renkl, & Sweller, 2003, 2004; Van Merriënboer, Kester & Paas, 2006). One way to manage intrinsic load is by applying a so called part-whole approach, in which the number of information elements and interactions between elements is initially reduced by simplifying the tasks, after which more and more elements and interactions are added (e.g., Van Merriënboer, Kester & Paas, 2006). An effective way to increase germane load is by increasing the variability of learning tasks (Paas & Van Merriënboer, 1994).

The authors in this special issue continue the research of identifying strategies that make learning environments and instructions more effective, so that learners will be better able to transfer their newly acquired knowledge and skills into new and familiar problem solving situations. Of the 16 papers, 8 papers, hereby, focus on different aspects of multimedia learning environments and the influence of prior knowledge, 4 papers scrutinize learning task characteristics, and 4 papers focus on additional tasks features which engage learners in productive learning activities.

Current Research Topics

Multimedia Learning Environments

According to Baddeley (2000), working memory consists of a central executive and three slave systems, the phonological loop, the visuospatial sketchpad and the episodic buffer. The central executive regulates and controls incoming information and it coordinates the three slave systems. The phonological loop and the visuospatial sketchpad are responsible for processing auditory and visual information respectively, and the episodic buffer organizes information in time and thus helps us memorize chronological order. Well-designed multimedia learning environments aim to make optimal use of the three slave systems by presenting a mix of static or dynamic verbal information in different modalities and static or dynamic pictorial information. Here, three studies focus on static multimedia learning environments while the other five studies focus on dynamic multimedia learning environments, that is, animations.

Static multimedia learning environments. Main research focus of researchers who study static multimedia learning environments is still the interplay between pictorial information and verbal information presented in different modalities, namely, aurally or visually. Park, Moreno, Seufert and Brünken (this issue) investigated the effects of seductive details (i.e., non-redundant, irrelevant information) and modality (i.e., text vs. narration) on learning about the structure and function of a cellular molecule responsible for the synthesis of ATP. Purpose of their study is to shed light on the conflicting results from previous seductive-details-studies by investigating the interaction between the presentation of seductive details and the modality of the presented verbal information. Lee and Kalyuga (this issue) studied the multimedia redundancy effect in using pinyin to learn the Chinese language. Common practice in teaching Chinese with the aid of pinyin (i.e., a phonetic transcription system based on the alphabet) is that Chinese characters (i.e., pictorial information), pinyin (i.e., visual, verbal information) and the pronunciation of the characters (i.e., redundant auditory, verbal information) are presented simultaneously. Lee and Kalyuga are interested if a multimedia redundancy effect occurs with this material and, if so, whether students with different levels of prior knowledge are affected differently by it.

Wetzels, Kester and Van Merriënboer (this issue) use a static multimedia learning environment to teach students about the functioning of the heart. They are interested in the effects of two prior knowledge activation strategies, namely, mobilization or perspective taking on subsequent learning. Low-prior-knowledge students and high-prior-knowledge students activated their prior knowledge based on a schematic picture of the heart and according to one of the two strategies before working on a sequence of learning tasks. The aim of their study was to find out if different prior knowledge activation strategies have different effects on learning for students with different levels of prior knowledge.

Dynamic multimedia learning environments. Main challenge for researchers who use dynamic multimedia learning environments is to help students deal with the transient nature of the dynamic information presented in these environments. The idea is that transient information places a heavy burden on working memory because it requires students to keep previously presented information active in working memory while processing the rest of the ongoing information. Schmidt-Weigand and Scheiter (this issue) and Kühl, Scheiter, Gerjets and Edelmann (this issue) study under which conditions the verbal information that accompanies an animation helps learning from it. Schmidt-Weigand and Scheiter varied the extent to which the spatial verbal information overlapped the spatial information conveyed by the animation to investigate the multimedia redundancy effect. Kühl, Scheiter, Gerjets and Edelmann compared the effects of written versus spoken text that explains an animation, on learning. Their study is prompted by the fact that dynamic learning material does not always lead to enhanced learning as compared to static learning material even in domains in which animated learning material seems the most logical choice (e.g., fish locomotion). They aimed to find out if the effectiveness of an animation for learning is mediated by the presentation modality of accompanying text.

Amadieu, Mariné and Laimay (this issue) and De Koning, Tabbers, Rikers and Paas (this issue) try to help students overcome the disadvantages of presenting transient information for learning by providing cues during an animation to guide students' attention to relevant parts or aspects of the animation. Besides looking at the effects on learning of animations with or without cues, Amadieu, Mariné and Laimay (this issue) also focused on the effect of repeated presentation of the same animation on learning while De Koning, Tabbers, Rikers and Paas (this issue) also investigated the effects of the animation's speed on learning. In both studies it is assumed that the effectiveness of cues is highest when the transient nature of the animation is most prominent, that is, the first time an animation is played or when it is played at a high speed.

Spanjers, Wouters, van Gog and van Merriënboer (this issue) investigate yet another possibility to deal with the transient nature of animations, namely, segmentation. They investigated the expertise reversal effect in learning from animated, worked examples. They assume that segmentation of animations is primarily effective for low-prior-knowledge learners while high-prior-knowledge learners will benefit more from uninterrupted animations.

Task Characteristics

Task characteristics, as learner characteristics and task/learner interactions, influence effective complex cognitive skill acquisition and affect CL (Paas & van Merriënboer, 1994). For example, a complex task has more constituent skills that must be coordinated and thus is likely to yield a higher intrinsic load than a simple task. In addition, for novices, instruction involving worked examples yields more effective learning than instruction consisting of solving the equivalent problems (Sweller, 1988). So, studying worked examples is an effective way to reduce extraneous load. The papers summarized here study the learning or affective effects of different task characteristics.

F. Kirschner, Paas, and Kirschner (this issue) used geometrical shapes to explore how learners working in groups and learners working individually differ depending on the task complexity (low, high). Inspired by research on self- and group-efficacy, the authors investigate an alternative affective explanation of the results by measuring the expected mental effort prior to task performance. Learners who work collaboratively on high-complexity tasks are expected to be more confident in being able to successfully complete the task than learners who work independently. Also in the geometrics domain, Schwonke, Renkl, Salden, and Aleven (this issue) focused on the effects of task support. More specifically, their study investigated the effects of different ratios of presented solution steps in worked examples (i.e., high task support) and to-be-solved problems (i.e., low support) on cognitive skill acquisition. It was expected that the effectiveness of these different ratios will vary with the type of learning outcomes (i.e., procedural vs. conceptual knowledge) and the difficulty of the to-be-learned principles.

The study conducted by Kalyuga and Hanham (this issue) investigated whether the acquisition of transferable problem solving skills in complex technical tasks is enhanced when tasks explicitly instruct learners in generalized forms of schematic knowledge structures as compared to direct instruction in specific knowledge and skills only. It was assumed that explicit instruction that emphasizes generalized schematic frameworks of a domain may direct learner's attention toward the essential task features and thus enhance transfer.

Finally, Berthold, Röder, Knörzer, Kessler, and Renkl (this issue) conducted an experiment with tax law tasks including conceptually-oriented explanation prompts. The authors assumed that tasks including prompts focus learners' attention on conceptual aspects but not on procedural aspects. Conceptually-oriented explanation prompts, constructed to induce focused processing of the central domain principles included in instructional explanations, were expected to foster conceptual knowledge, the specificity of explanations, and the number of elaborations on domain principles. In addition, the authors studied the effects of tasks including conceptually-oriented prompts on procedural knowledge.

Learner Engagement

Appropriate instructional designs decrease extraneous cognitive load but increase germane cognitive load (P. A. Kirschner, 2002). The latter being associated with the effort that is required for the acquisition and automation of cognitive schemas (i.e., learning). By assigning learners an active role in their own learning process, they can be stimulated to invest this important effort, and consequently improve their learning (Paas, 2003). The papers described in this paragraph all assign learners an active role in their own learning process.

The paper by Corbalan, Kester, and Van Merriënboer (this issue) focuses on facilitating learning by allowing learners to select their own, personally relevant learning tasks (i.e., learner-controlled instruction). It was predicted that the better learners were able to choose personally relevant and varied tasks, the better they would learn. Since, surface task features are more salient than structural task features and thus easier to recognize for novices, learner-control over surface task features was predicted to facilitate learning more than learner-control over structural features. To investigate this prediction an experiment with secondary school students studied the effects of learner-controlled selection of tasks that differed in their surface and structural features on learning effectiveness and efficiency in an electronic learning environment.

The paper by Mihalca, Salden, Corbalan, Paas, and Miclea (this issue) focuses on the role of prior knowledge in a student’s ability to effectively use given control over instruction. For this purpose, the learning effectiveness and efficiency of non-adaptive program-control and learner-control relative to adaptive program-control in learning genetics by students of different prior knowledge levels was assessed. With regard to prior knowledge, it was expected that the higher students' prior knowledge level, the more working memory capacity would be available to perceive their current learning state and instructional needs, and the better they would be able to manage their own instruction and learning. With regard to given control, non-adaptive program-control was expected to be insensitive to individual students’ learning needs, while the learner-controlled instruction might overload the students.

The paper by Schwamborn, Thillmann, Opfermann, and Leutner (this issue) encouraged learners to actively engage in active cognitive processing by asking them to generate visualizations that correspond to the main elements and relations described in a text and/or study provided visualizations. They varied their instruction according to a 2x2 factorial design with "learner-generated pictures" and "provided pictures" as factors, and investigated whether positive effects on text comprehension for learning with provided and learner-generated pictures can be found. In addition, it was investigated whether this processing of different forms of pictures has a differential impact on cognitive load that might even mediate the effects on comprehension.

Finally, the paper by Zhang and Ayres (this issue) used a collaborative learning environment to assign learners an active role in their learning process. Using a webpage design task they compared the learning effects of two collaborative learning strategies with an individualized learning strategy. Because learners in the collaborative learning condition would have the benefit of sharing the cognitive load imposed by the task among each other, it was hypothesized that collaborative approaches would outperform the individualized approach. After all, the freed up WM capacity at the group member level could then be devoted to relevant learning processes.

Discussion

The clinching paper in this special issue is a discussion by P. A. Kirschner, Ayres, and Chandler (this issue) on the above mentioned 16 empirical papers. Focusing on more or less the same three categorisations: xxx, xxx and xxx, they provide a summary, critical comments and future research directions for each paper, as well as for the overall future of CLT.

Acknowledgements

The guest editors would like to acknowledge Yvonne Anders, Paul Ayres, Mireille Bétrancourt, Daniel Bodemer, Jean-Michel Boucheix, Geraldine Clarebout, Willem de Grave, Paul Ginns, Egbert Harskamp, Tatjana Hilbert, Tim Külh, Jose Emilio Labra, Yin-kum Law, Matthias Nückles, Maria Opfermann, Fred Paas, Jan Plass, Martin Reisslein, Jim Ridgway, Remy Rikers, Ralf Rummer, John Sweller, Huib Tabbers, André Tricot, Denise Whitelock, Eric Wiebe, Jorg Wittwer, Pieter Wouters, who have acted as reviewers on this special issue.

References

Amadieu, F., Mariné, C., & Laimay, C. (this issue). The attention-guiding effect and cognitive load in the comprehension of animations. *Computers in Human Behavior, xx*, xxx-xxx

Atkinson, R. K., Derry, S. J., Renkl, A., & Wortham, D. W. (2000). Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research, 70*, 181-214.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47-89). New York: Academic Press.

Baddeley, A.D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*, 417–423.

Berthold, K., Röder, H., Knörzer, D., Kessler, W., & Renkl, A. (this issue). The double-edged effects of explanation prompts. *Computers in Human Behavior, xx*, xxx-xxx

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology, 4*, 55-81.

Corbalan, G., Kester, L., & Van Merriënboer, J. J G. (this issue). Learner-controlled selection of tasks with different surface and structural features: Effects on transfer and efficiency. *Computers in Human Behavior*, *xx*, xxx-xxx

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of metal storage capacity. *Behavioral and Brain Sciences, 24*, 87-114.

De Groot, A. D. (1946). *Het denken van den schaker* [Thinking in chess players]. Amsterdam: Noord Hollandsche.

De Groot, A. D. (1978). *Thought and choice in chess* (Revised translation of De Groot, 1946; 2nd ed.). The Hague: Mouton Publishers.

De Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (this issue). Attention cueing in an instructional animation: The role of presentation speed. *Computers in Human Behavior, xx*, xxx-xxx

Kalyuga, S., & Hanham, J. (this issue). Instructing in generalized knowledge structures to develop flexible problem solving skills. *Computers in Human Behavior, xx*, xxx-xxx

Kirschner, F., Paas, F., & Kirschner, P. A. (this issue). Superiority of collaborative learning with complex tasks: A research note on an alternative affective explanation. *Computers in Human Behavior, xx*, xxx-xxx

Kirschner, P. A. (2002). Can we support CSCL? Educational, social and technological affordances for learning. In P. Kirschner (Ed.), *Three worlds of CSCL: Can we support CSCL*. Inaugural address, Open University of the Netherlands.

Kühl, T., Scheiter, K., Gerjets, P., & Edelmann, J.(this issue). The influence of text modality on learning with static and dynamic visualizations. *Computers in Human Behavior, xx*, xxx-xxx

Lee, C. H., & Kalyuga, S. (this issue). Effectiveness of on-screen pinyin in learning chinese: An expertise reversal for multimedia redundancy effect. *Computers in Human Behavior, xx*, xxx-xxx

Mihalca, L., Salden, R. J. C. M, Corbalan, G., Paas, F., & Miclea, M. (this issue). Effectiveness of cognitive-load based adaptive instruction in genetics education. *Computers in Human Behavior, xx*, xxx-xxx

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81–97.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*, 1-4.

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science, 32*, 1-8.

Paas, F., Tuovinen, J., Van Merriënboer, J. J. G., & Darabi, A. (2005). A motivational perspective on the relation between mental effort and performance: Optimizing learners' involvement in instructional conditions. *Educational Technology, Research and Development*, *53*, 25–33.

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*, 63-71.

Paas, F., Van Gog, T., Kirschner, F., Marcus, N., Ayres, P., & Sweller, J. (2008). Interdisciplinary perspectives on cognitive load research as a key to tackle challenges of contemporary education. In J. Zumbach, N. Schwartz, T. Seufert, & L. Kester (Eds.), *Beyond knowledge: The legacy of competence* (pp. 7-9). Dordrecht, the Netherlands: Springer.

Paas, F., & Van Merriënboer, J. J. G. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational Psychology Review, 6,* 51-71.

Park, B., Moreno, R., Seufert, T., & Brünken, R. (this issue). Does cognitive load moderate the seductive details effect? A multimedia study. *Computers in Human Behavior, xx*, xxx-xxx

Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58*, 193-198.

Schmidt-Weigand, F., & Scheiter, K. (this issue). The role of spatial descriptions in learning from multimedia. *Computers in Human Behavior, xx*, xxx-xxx

Schwamborn, A., Thillmann, H., Opfermann, M. & Leutner, D. (this issue). Cognitive load and instructionally supported learning with provided and learner-generated visualizations. *Computers in Human Behavior, xx*, xxx-xxx

Schwonke, R., Renkl, A., Salden, R. J. C. M, & Aleven, V. (this issue). Effects of different ratios of worked solution steps and problem solving opportunities on cognitive load and learning outcomes. *Computers in Human Behavior, xx*, xxx-xxx

Simon, H. A. (1974). How big is a chunk? *Science*, *183*, 482-488.

Simon, H. A., & Gilmartin, K. J. (1973). A simulation of memory for chess positions. *Cognitive Psychology, 5*, 29-46.

Spanjers, I. A. E., Wouters, P., Van Gog, T., & Van Merriënboer, J. J. G. (this issue). An expertise reversal effect of segmentation in learning from animated worked-out examples. *Computers in Human Behavior, xx*, xxx-xxx

Sweller, J. (1988). Cognitive load during problem solving: effects on learning. *Cognitive Science, 12,* 257-285.

Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science, 32,* 9-31.

Sweller, J., Van Merriënboer, J. J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*, 251-295.

Van Gog, T., & Paas, F. , Marcus, N., Ayres, P., & Sweller, J. (2009). The mirror Neuron system and observational learning: implications for the effectiveness of dynamic visualizations. *Educational Psychology Review, 21,* 21-30.

Van Merriënboer, J. J. G., Kester, L. & Paas, F. (2006). Teaching complex rather than simple tasks: Balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology, 20*, 343-352.

Van Merriënboer, J. J. G., & Kirschner, P. A. (2007). *Ten steps to complex learning*. Mahwah, NJ: Lawrence Erlbaum.

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review, 17*, 147–177.

Wetzels, S. A. J., Kester, L., &. Van Merriënboer, J. J. G. (this issue). Adapting prior knowledge activation: Mobilisation, perspective taking, and learners' prior knowledge. *Computers in Human Behavior, xx,* xxx-xxx

Zhang, L., Ayres, P., & Chan, K. K. (this issue). Examining different types of collaborative learning in a complex computer-based environment: A cognitive load approach. *Computers in Human Behavior, xx*, xxx-xxx